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(54) **ELECTRICALLY HEATED CATALYST DEVICE AND ITS MANUFACTURING METHOD**

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(Continued)

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CPC F01N 3/2828; B01D 53/96; B01J 35/04; Y02T 10/26; Y02T 29/49099

USPC 422/174

See application file for complete search history.

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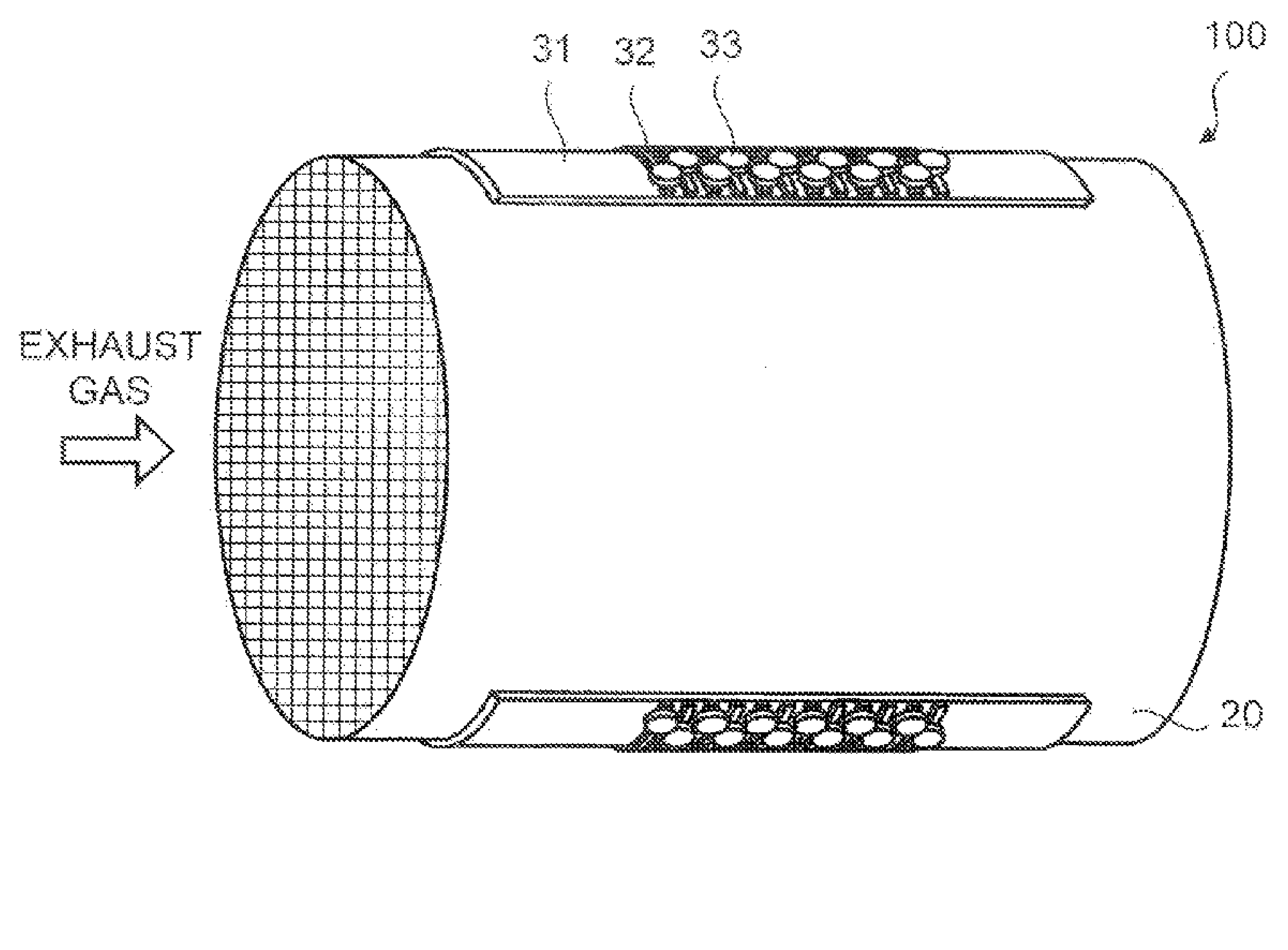
(57) **ABSTRACT**

An electrically heated catalyst device includes a catalyst support including a ceramics, on which a catalyst is supported, a pair of surface electrodes disposed on an outer surface of the catalyst support, the surface electrodes being disposed opposite to each other and extending in an axial direction of the catalyst support, and a wiring line that externally supplies electric power to the surface electrodes, in which the catalyst support is electrically heated through the surface electrodes. A wrought member made of metal is buried in the surface electrodes, the wrought member extending in the axial direction of the catalyst support. With the configuration like this, the spreading of electric currents in the catalyst-support axis direction can be maintained even when cracks occur in the catalyst-support circumference direction in the surface electrodes.

15 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

B01J 35/04	(2006.01)
H01C 17/06	(2006.01)
H01C 17/28	(2006.01)
B01D 53/96	(2006.01)
F01N 3/20	(2006.01)
F01N 3/28	(2006.01)

(52) **U.S. Cl.**

CPC ***F01N 3/2828*** (2013.01); ***H01C 17/06*** (2013.01); ***H01C 17/28*** (2013.01); *Y02T 10/26* (2013.01); *Y10T 29/49083* (2015.01); *Y10T 29/49099* (2015.01); *Y10T 29/49345* (2015.01)

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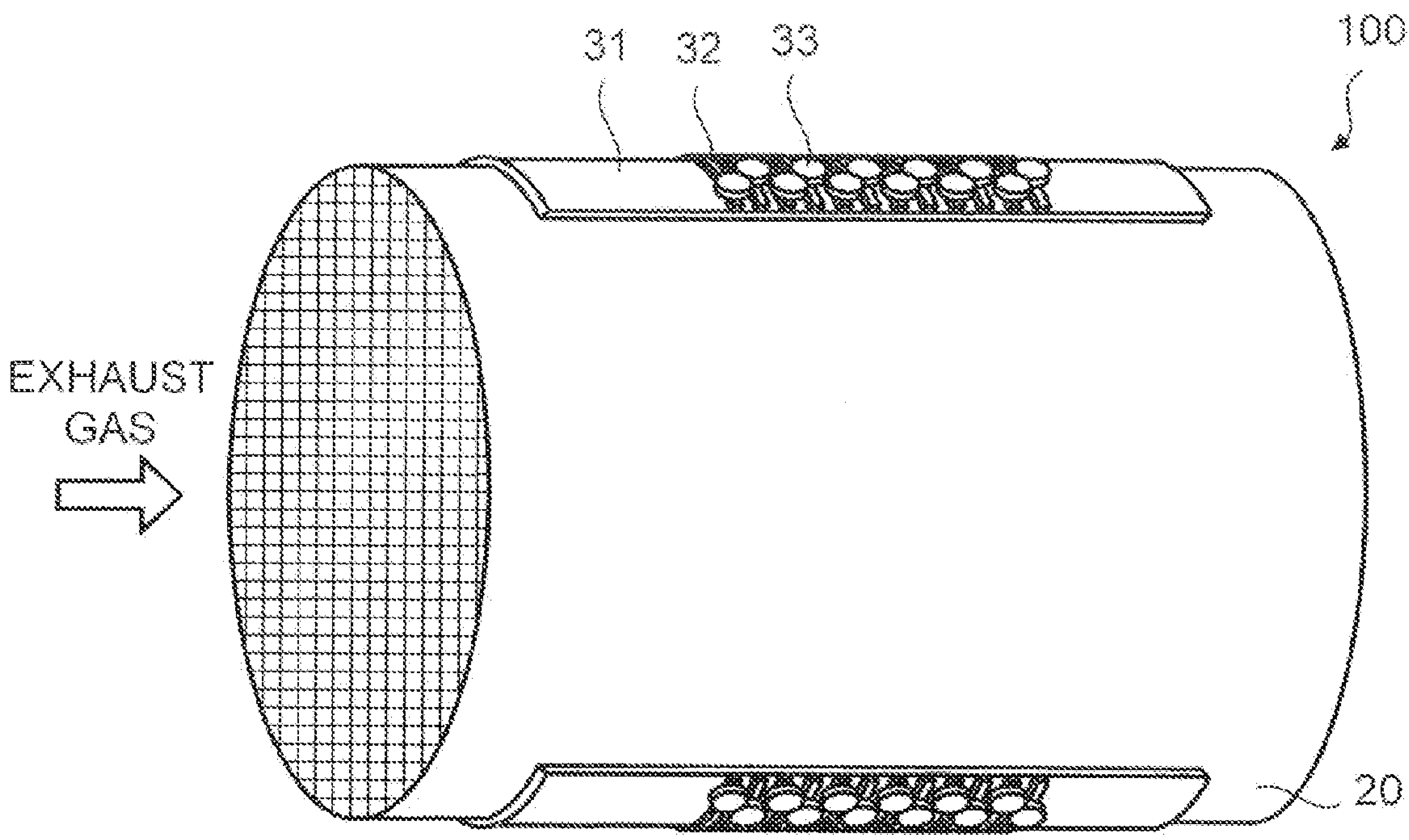


Fig. 1

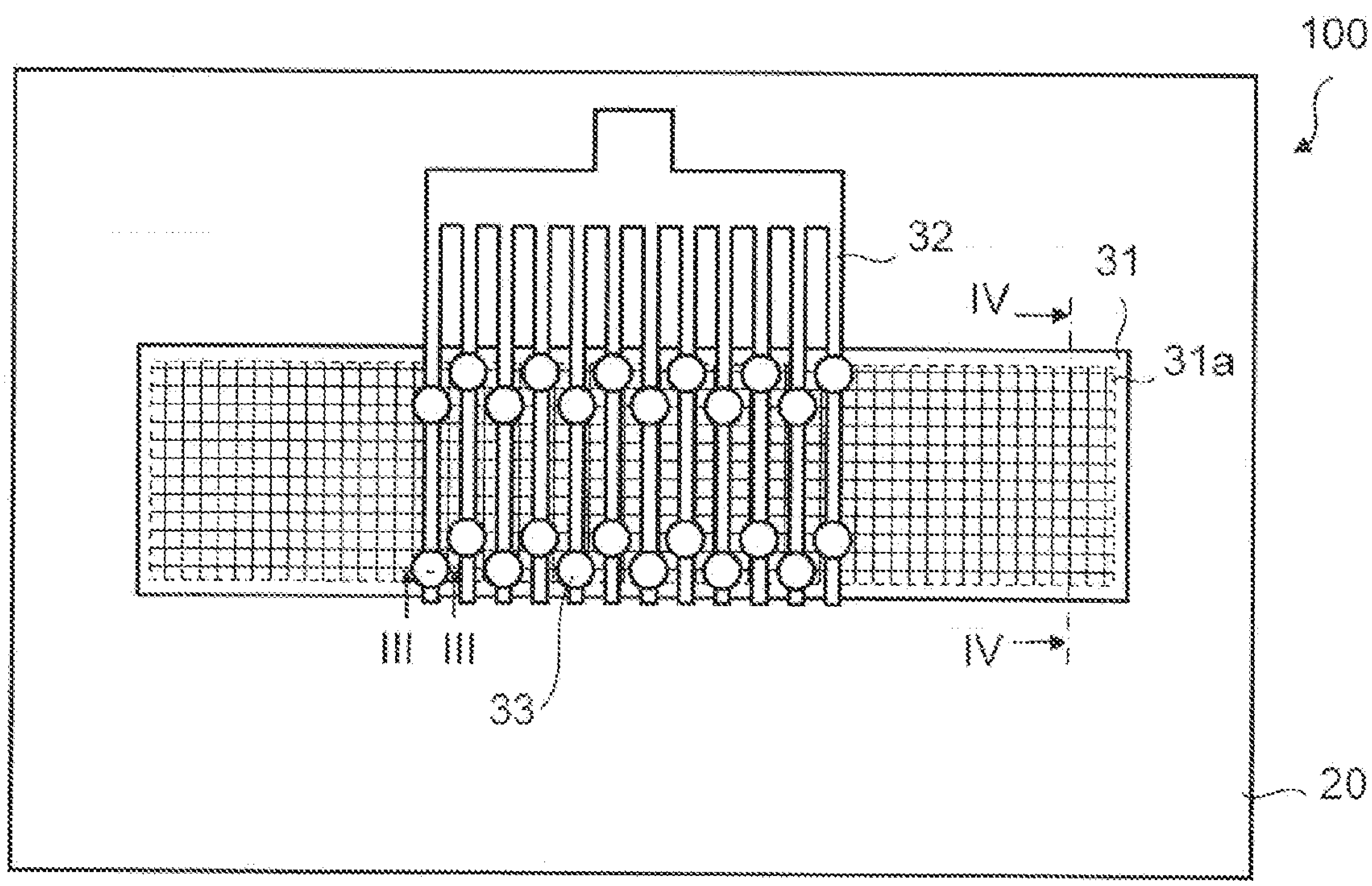


Fig. 2

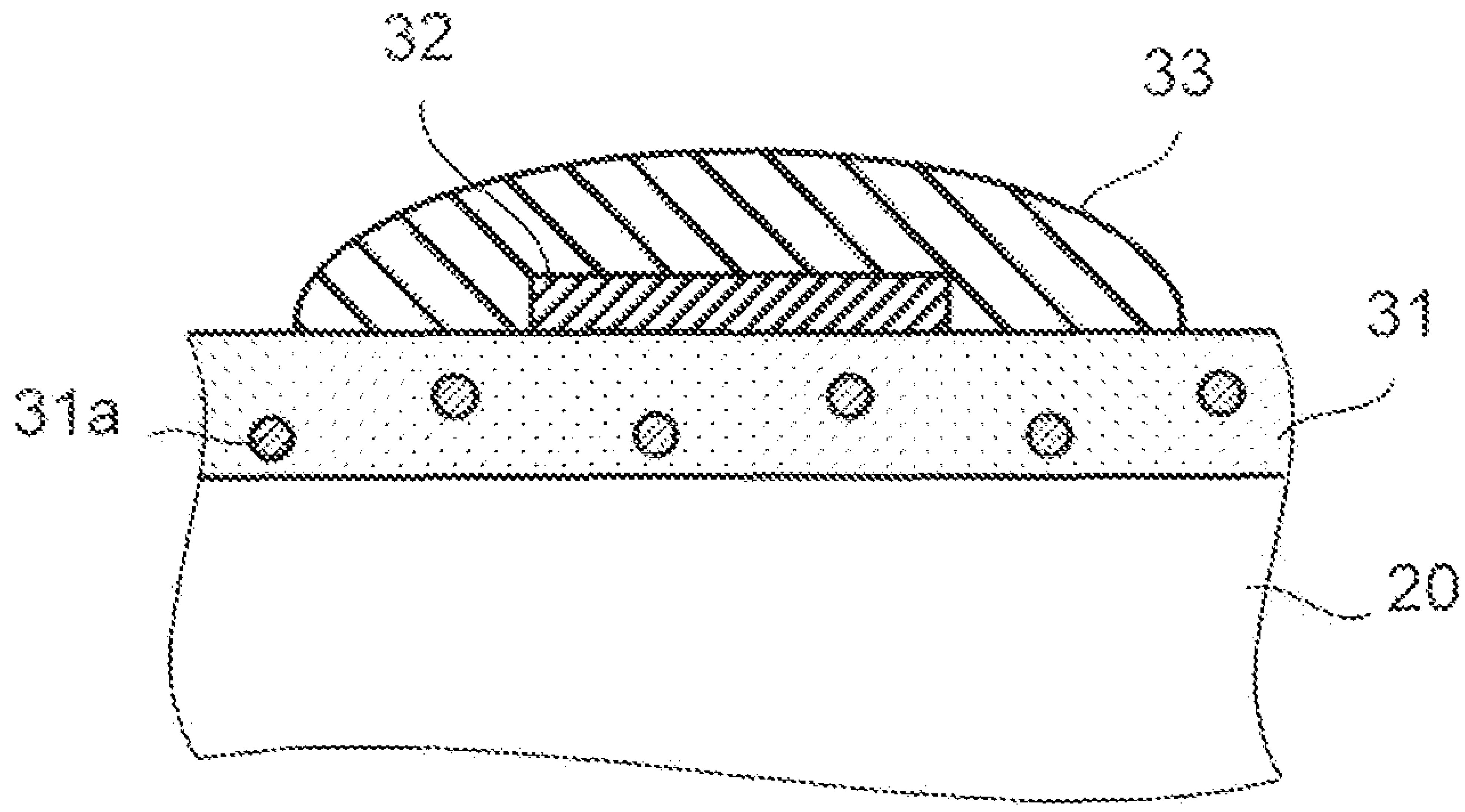


Fig. 3

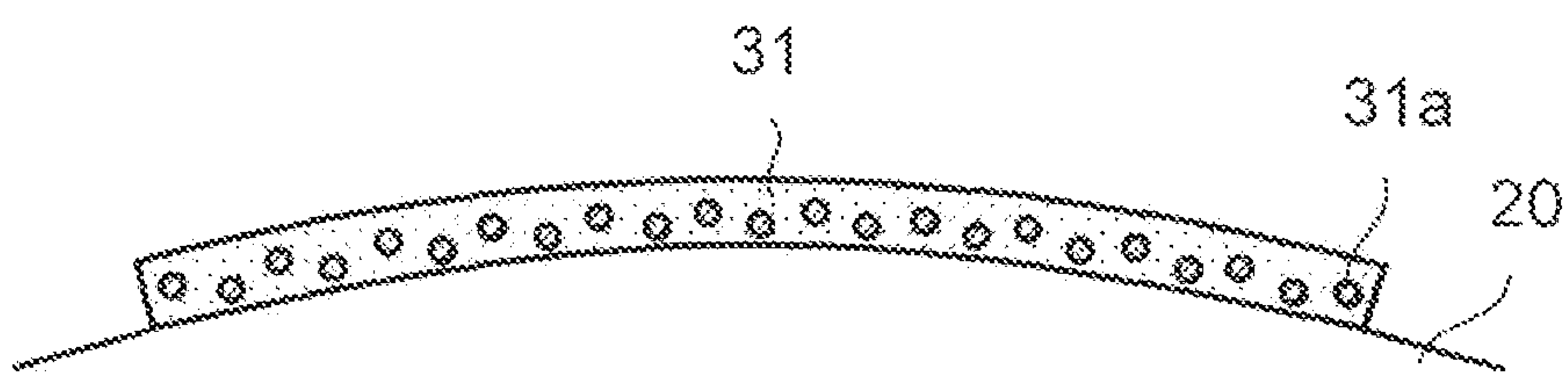


Fig. 4

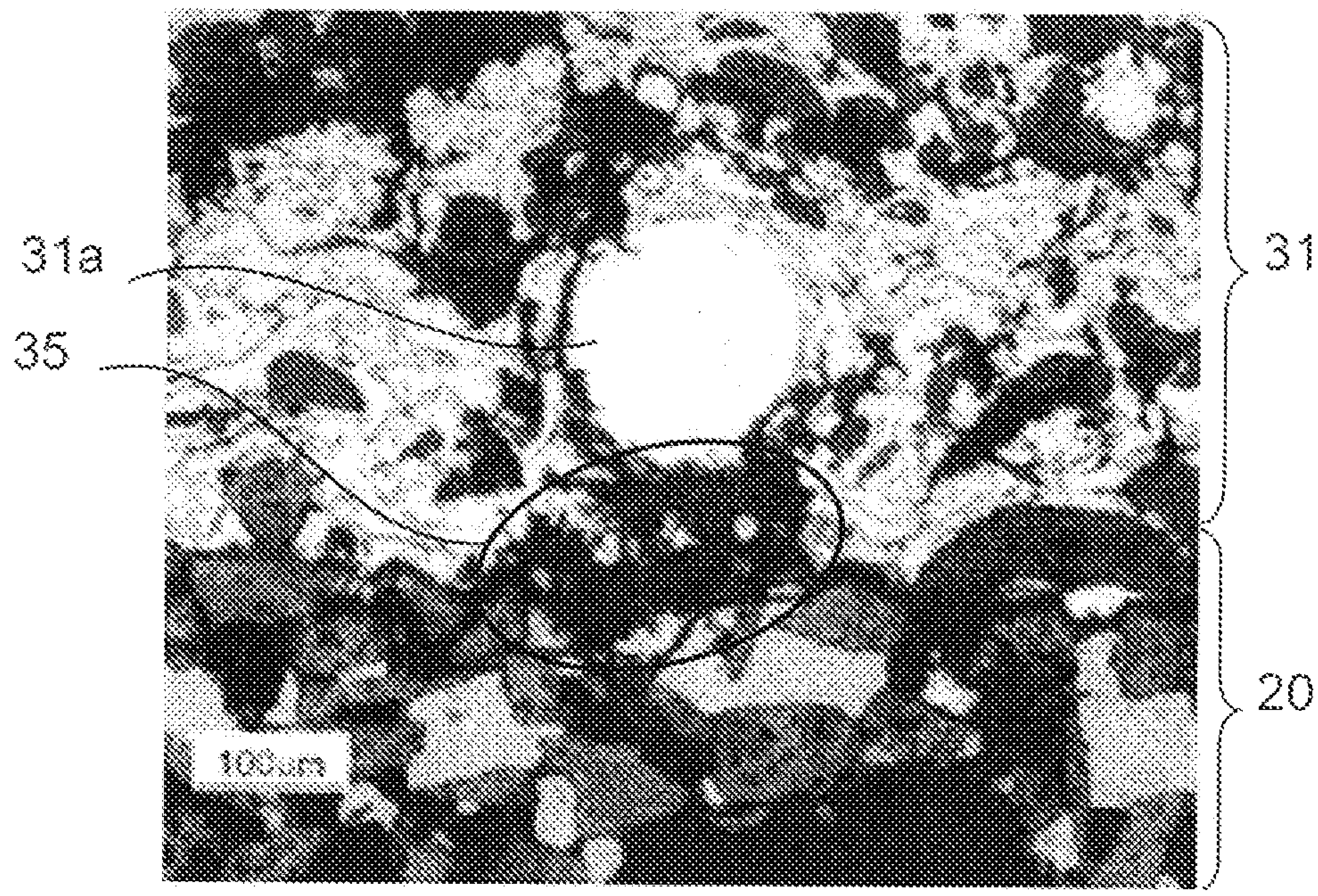
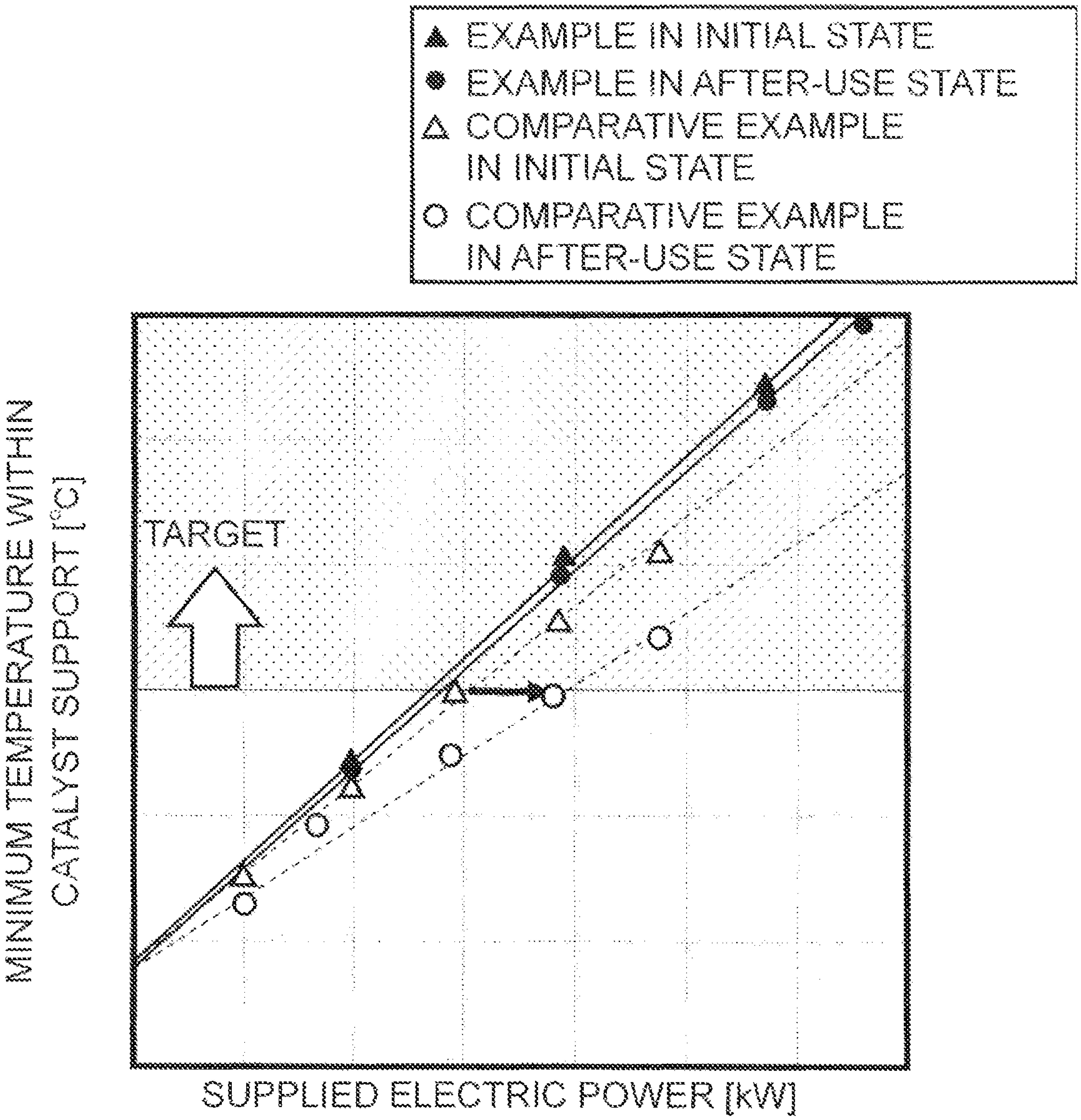
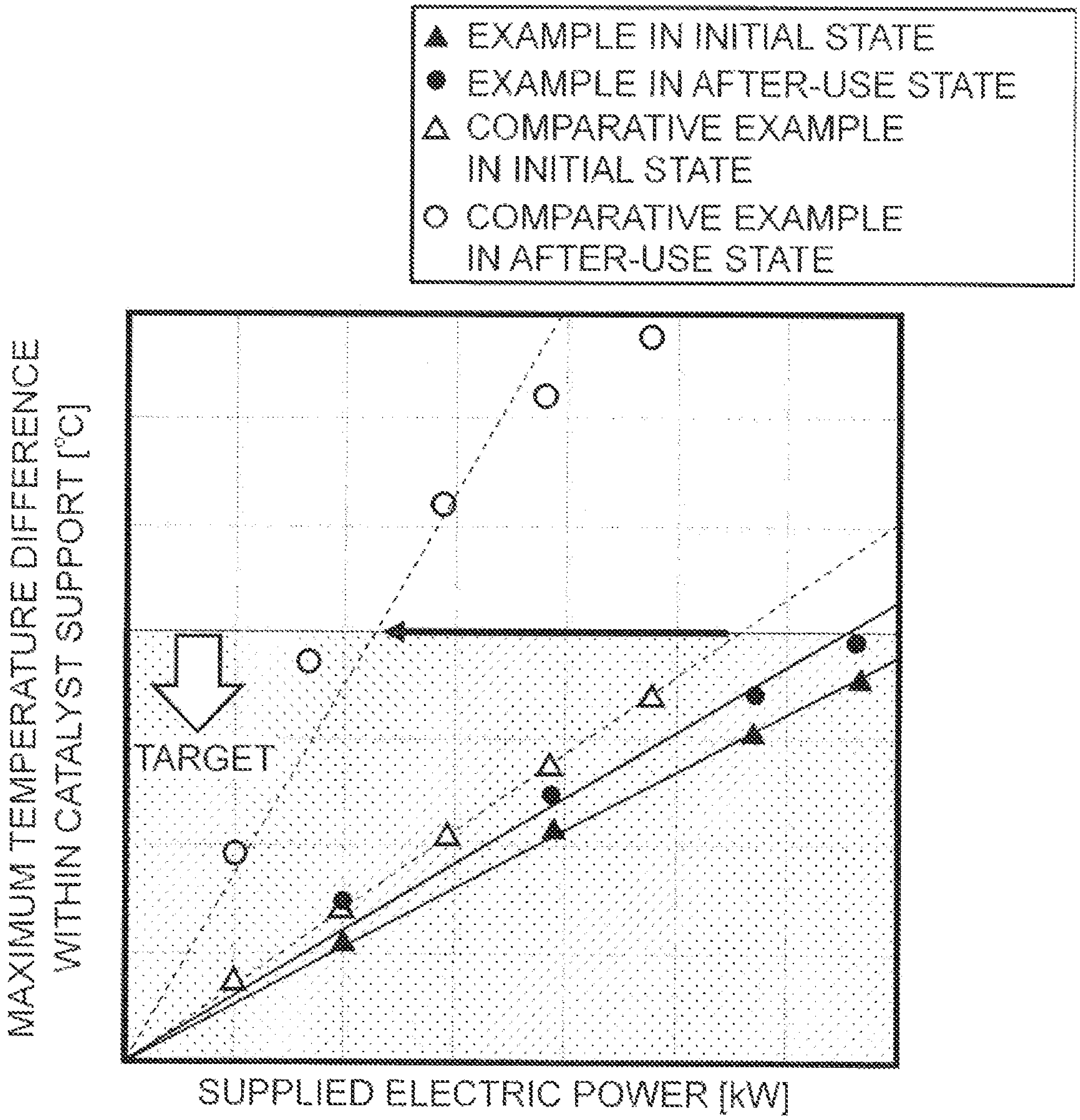


Fig. 5



EXAMPLE IN INITIAL STATE
EXAMPLE IN AFTER-USE STATE
COMPARATIVE EXAMPLE IN INITIAL STATE
COMPARATIVE EXAMPLE IN AFTER-USE STATE
TARGET
MINIMUM TEMPERATURE WITHIN CATALYST SUPPORT [°C]
SUPPLIED ELECTRIC POWER [kW]

Fig. 6



EXAMPLE IN INITIAL STATE
EXAMPLE IN AFTER-USE STATE
COMPARATIVE EXAMPLE IN INITIAL STATE
COMPARATIVE EXAMPLE IN AFTER-USE STATE
MAXIMUM TEMPERATURE DIFFERENCE WITHIN CATALYST SUPPORT [°C]
TARGET
SUPPLIED ELECTRIC POWER [kW]

Fig. 7

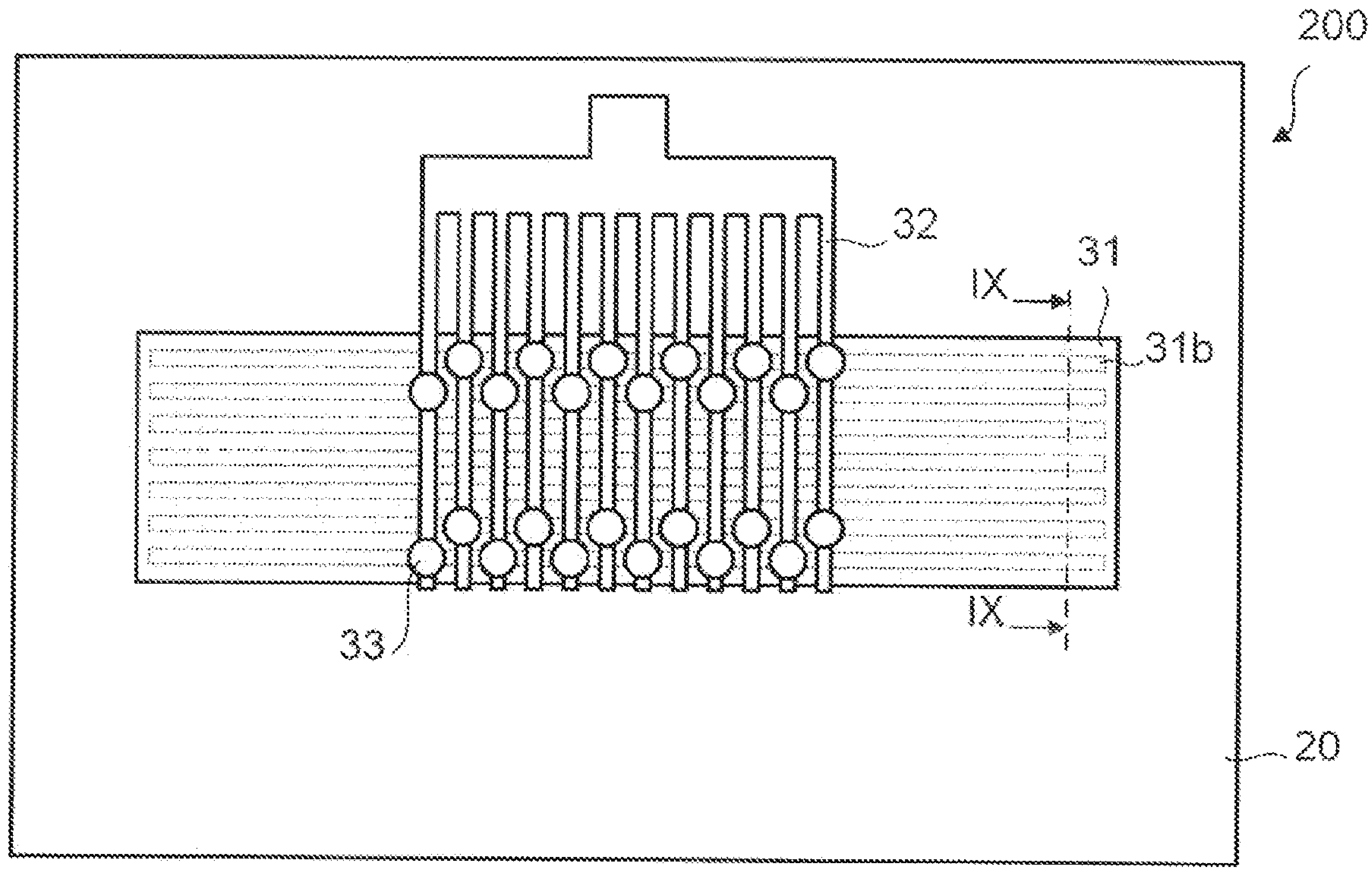


Fig. 8

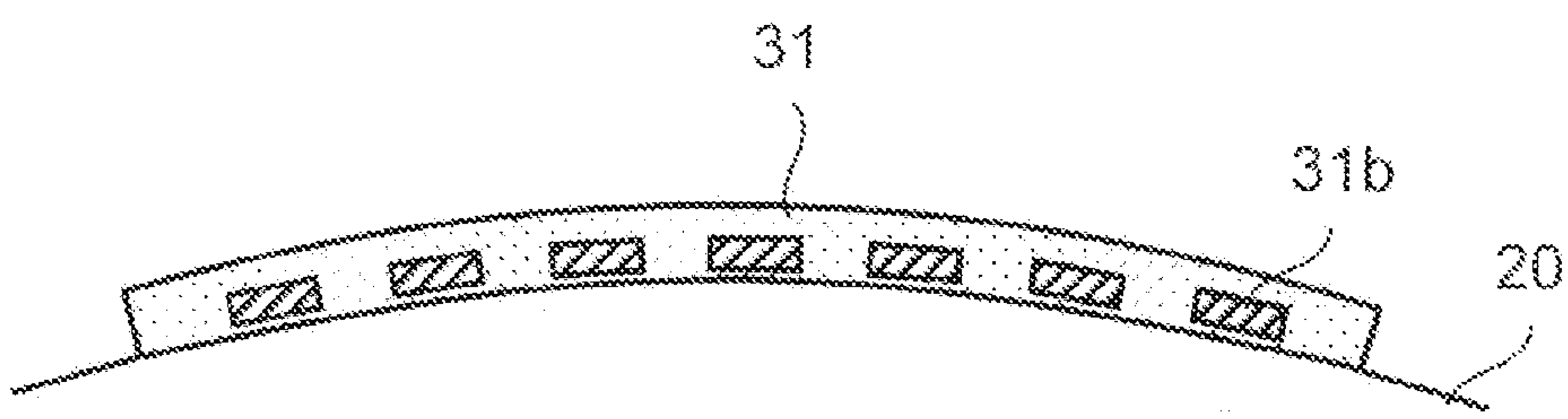


Fig. 9

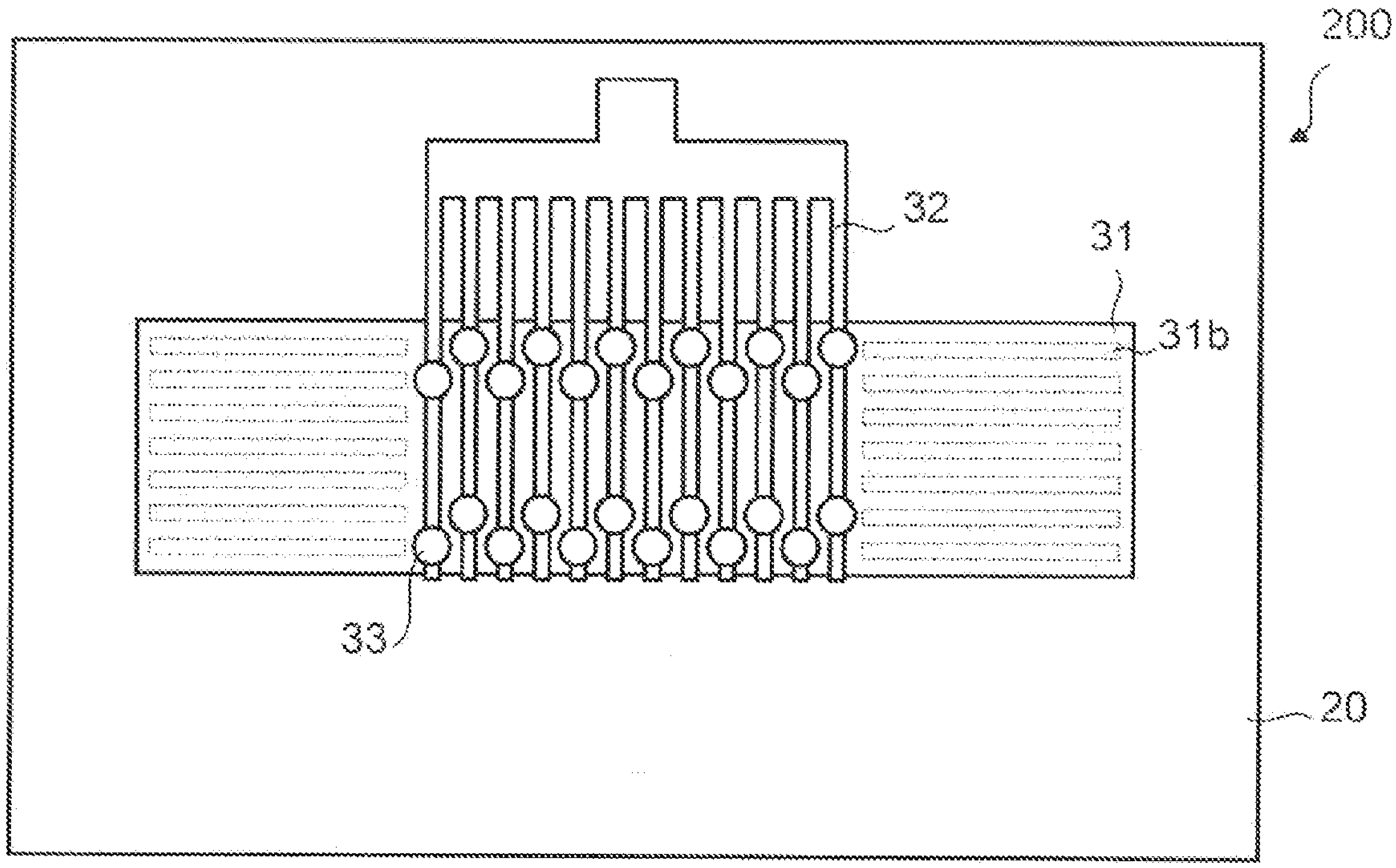


Fig. 10

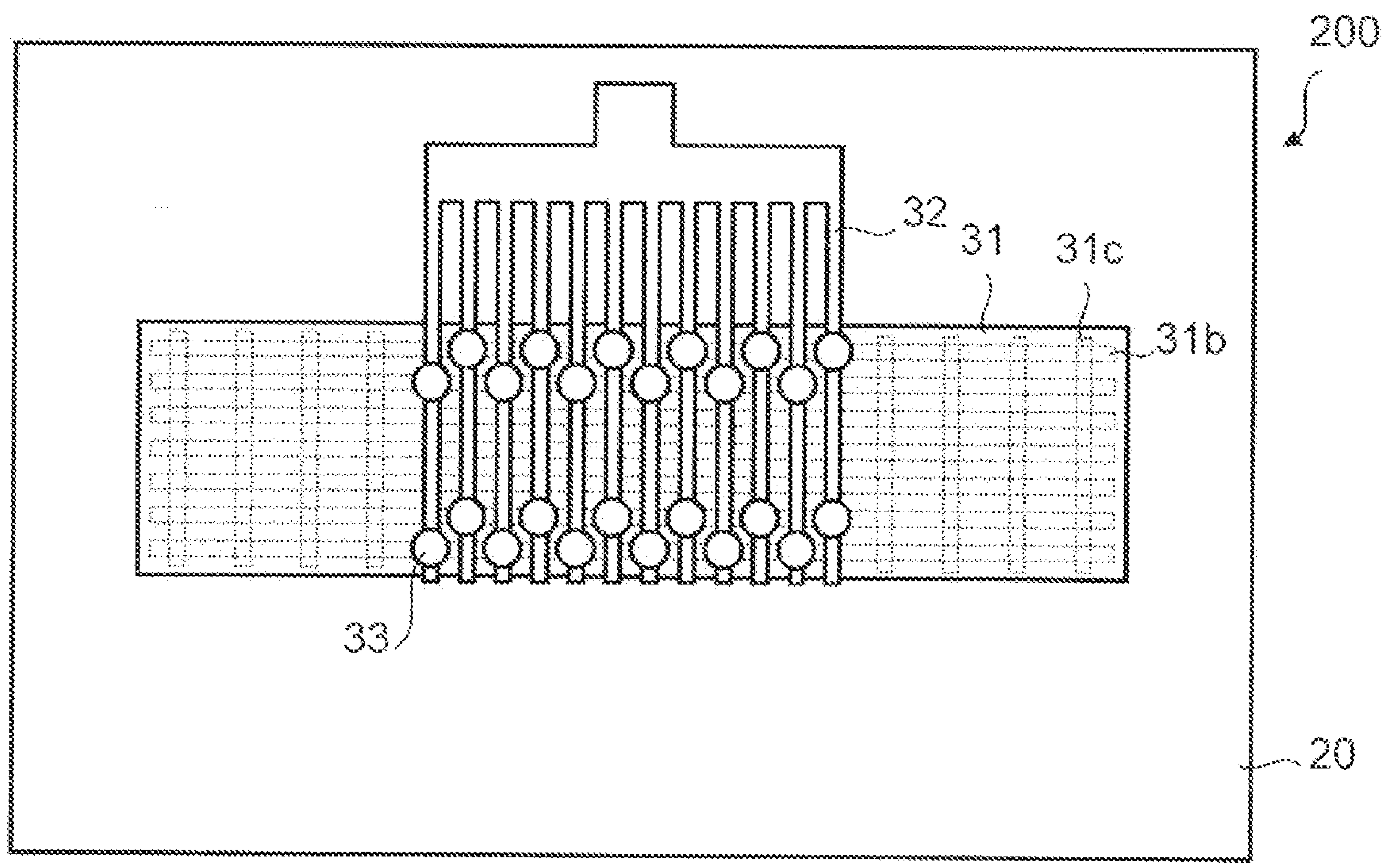


Fig. 11

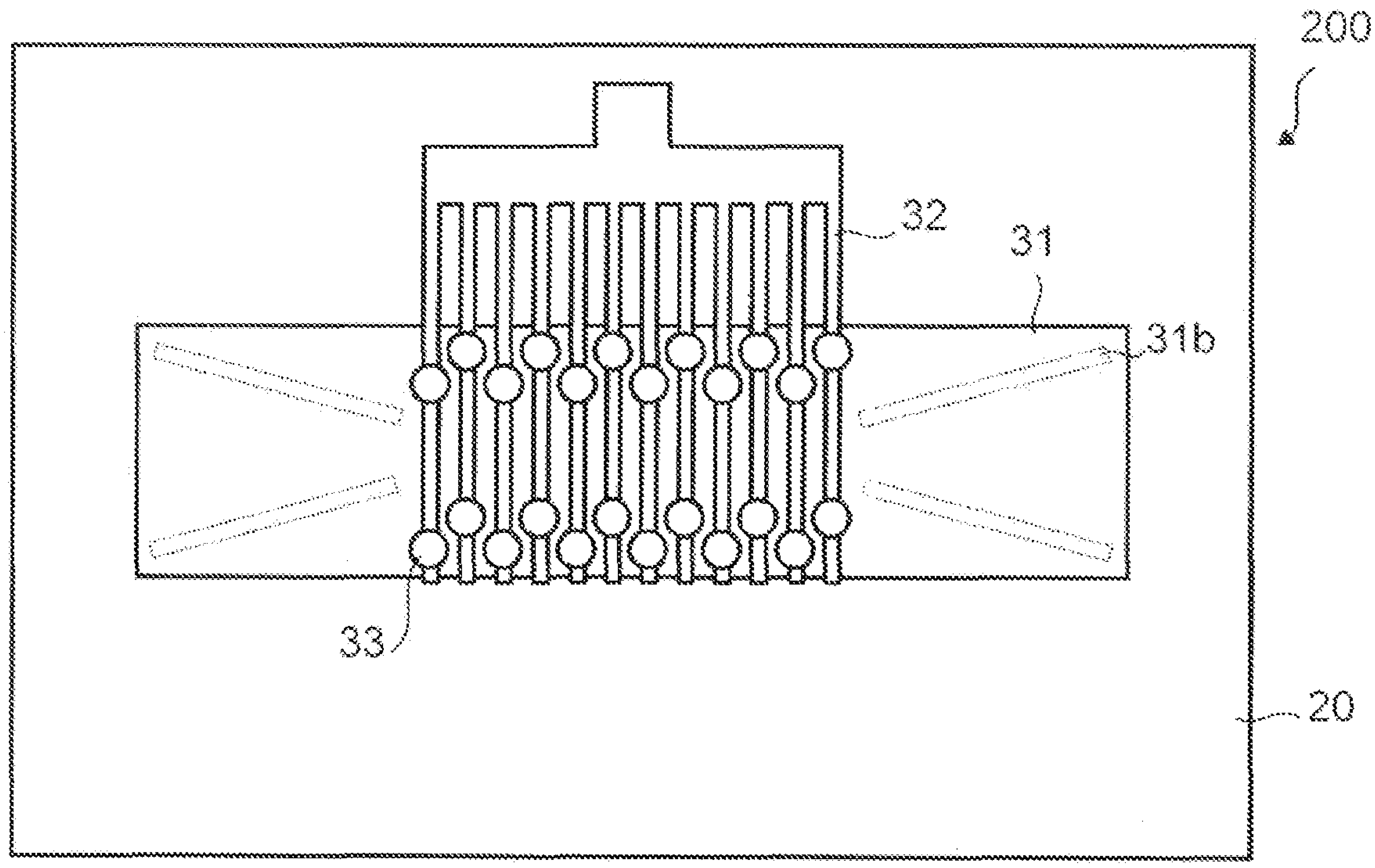


Fig. 12

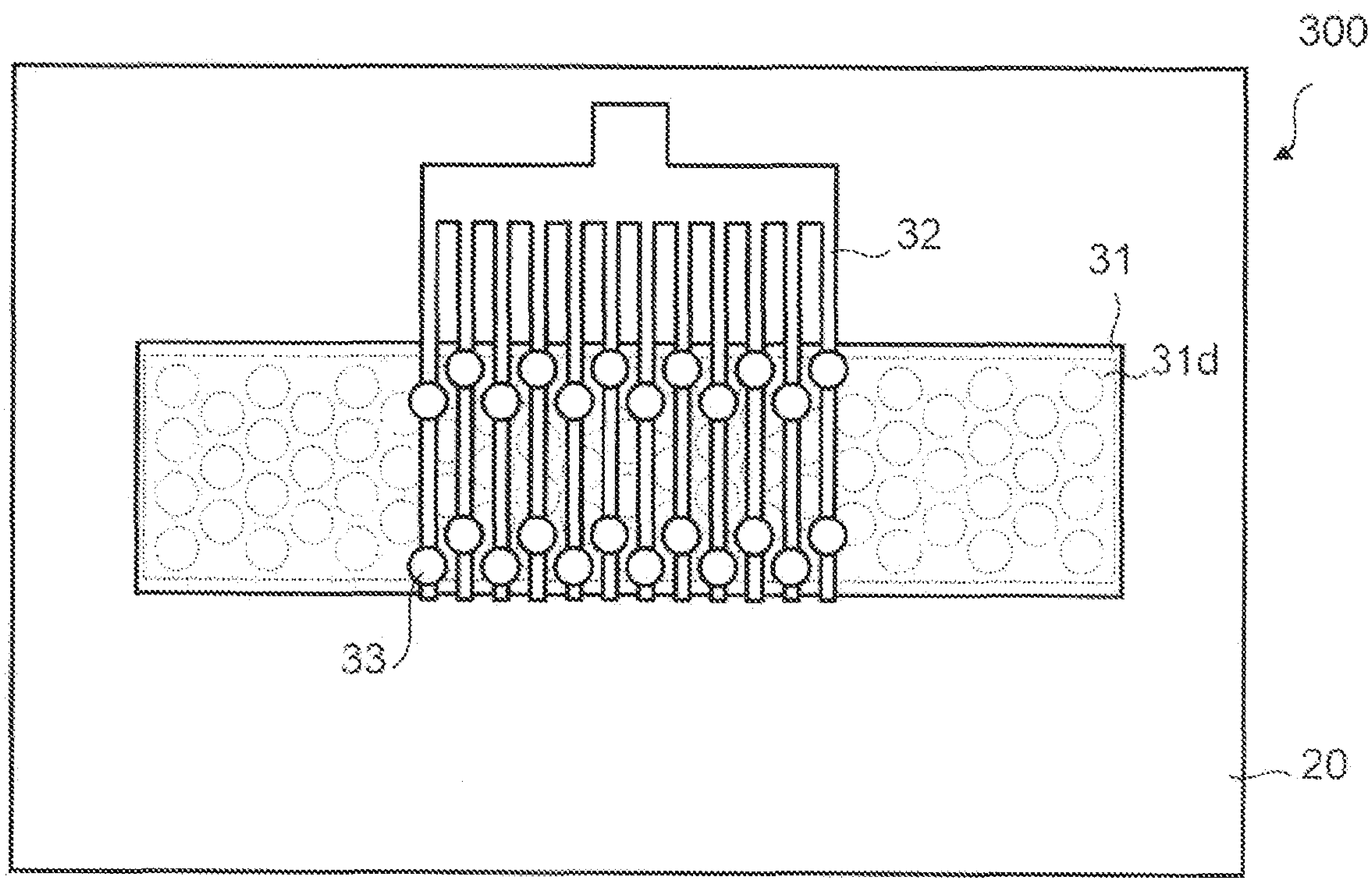


Fig. 13

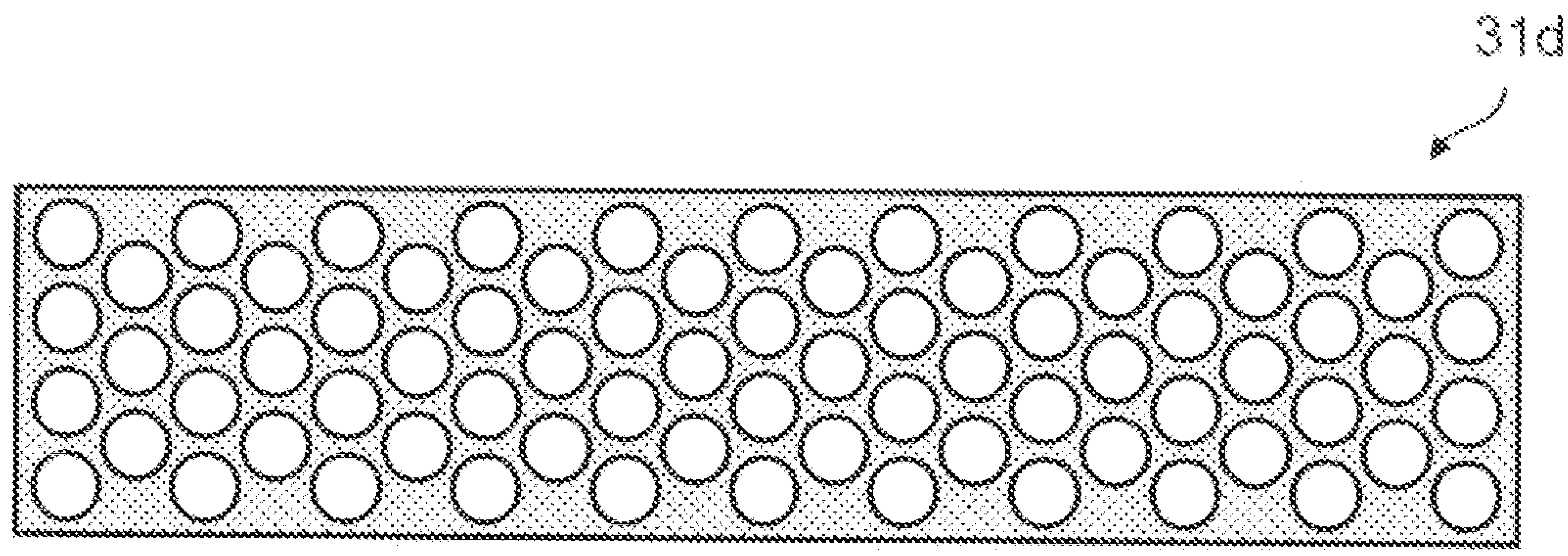


Fig. 14A

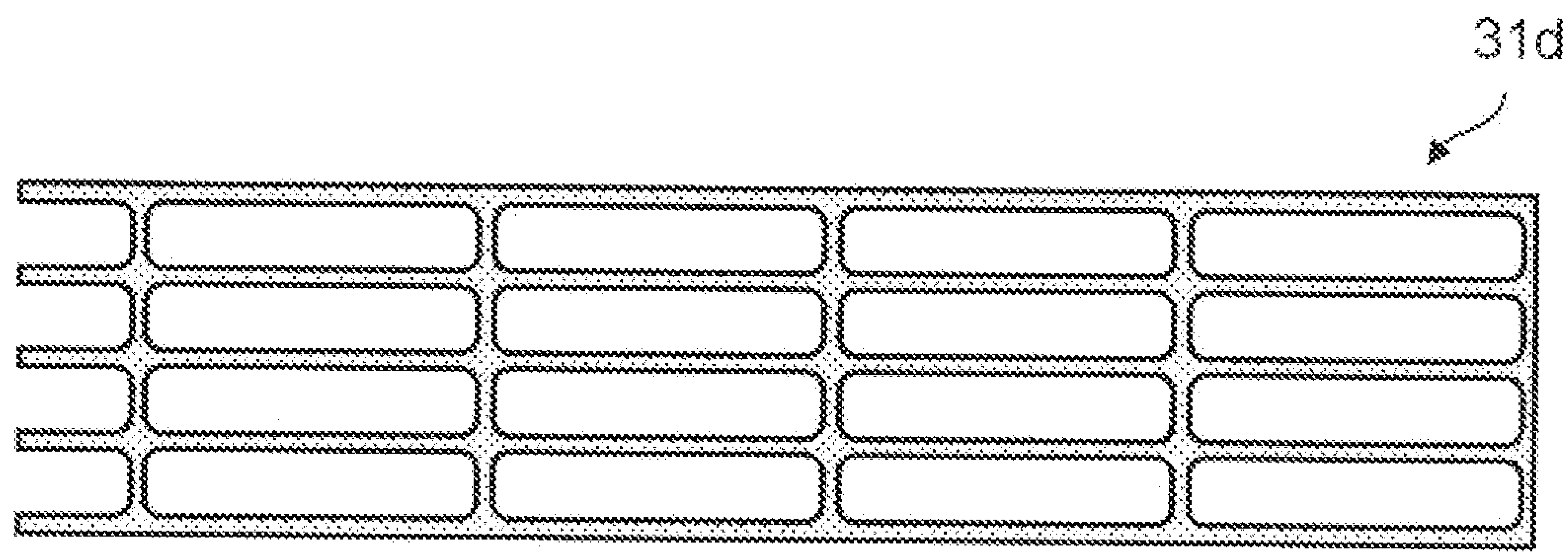


Fig. 14B

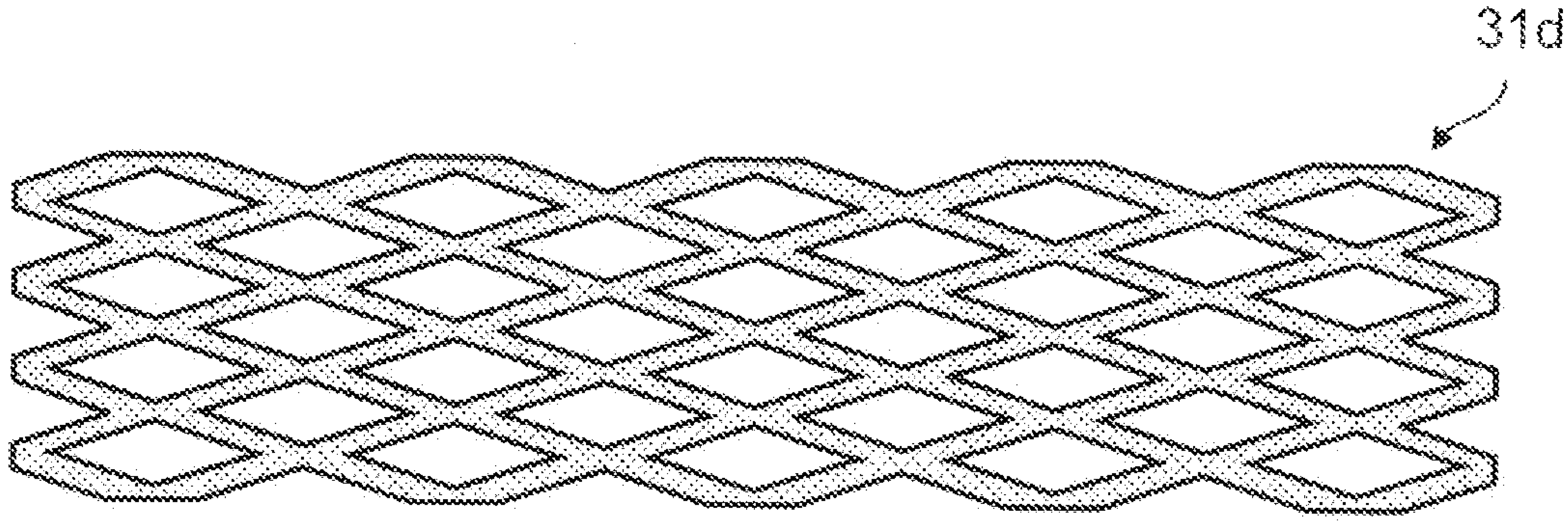


Fig. 14C

ELECTRICALLY HEATED CATALYST DEVICE AND ITS MANUFACTURING METHOD

TECHNICAL FIELD

The present invention relates to an electrically heated catalyst device and its manufacturing method.

BACKGROUND ART

In recent years, EHCs (electrically heated catalysts) are attracting attention as an exhaust purification device that purifies exhaust gases discharged from engines of automobiles and the like. In EHCs, it is possible to forcibly activate a catalyst by electrical heating even under such conditions that the temperature of the exhaust gas is low and thus the catalyst cannot be easily activated, such as immediately after the engine is started, and thereby to enhance the purification efficiency of the exhaust gas.

An EHC disclosed in Patent literature 1 includes a cylindrical catalyst support having a honeycomb structure on which a catalyst such as platinum and palladium is supported, and a pair of surface electrodes that are electrically connected to the catalyst support and disposed opposite to each other on the outer surface of the catalyst support. In this EHC, the catalyst supported on the catalyst support is activated by electrically heating the catalyst support between the pair of surface electrodes. In this way, unburned HC (hydrocarbon), CO (carbon monoxide), NOx (nitrogen oxide), and the like contained in an exhaust gas that passes through the catalyst support are removed by the catalytic reaction.

Since an EHC is disposed on an exhaust path of an automobile or the like, the material for the above-described surface electrode needs to have, in addition to the electrical conductivity, heat resistance, oxidation resistance at a high temperature, corrosion resistance in an exhaust-gas atmosphere, and the like. Therefore, as mentioned in Patent literature 1, metallic material such as a Ni—Cr alloy and an MCrAlY alloy (M is at least one material selected from Fe, Co and Ni) is used. The surface electrode is formed on the catalyst support by thermal spraying. Meanwhile, as for the material for the above-described catalyst support, ceramic material such as SiC (silicon carbide) is used. As a result, when the EHC is electrically heated, a thermal stress occurs due to the difference between the linear expansion coefficient of the metallic material forming the surface electrode and that of the ceramic material forming the catalyst support.

CITATION LIST

Patent Literature

Patent literature 1: Japanese Unexamined Patent Application Publication No. 2011-106308

SUMMARY OF INVENTION

Technical Problem

The inventor has found the following problem to be solved. The surface electrodes of an EHC are disposed so as to extend in the axial direction of the cylindrical catalyst support. Further, metal wiring lines are connected at the center in the catalyst-support axial direction in each surface electrode, and an electric current is supplied therethrough. This electric current spreads in the catalyst-support axial direction in each

surface electrode, so that the entire catalyst support is electrically heated between the pair of surface electrodes.

When the electrical heating is repeated, cracks occur in the surface electrodes in the catalyst-support circumference direction due to the above-described thermal stress and the spreading of electric currents in the catalyst-support axis direction is thereby hampered. As a result, there is a problem that the area near the connection points between the surface electrode and the metal wiring lines (the central area of the catalyst-support in the axial direction) is intensively heated.

The present invention has been made in view of the above-described circumstance, and an object thereof is to provide an electrically heated catalyst device capable of maintaining the spreading of electric currents in the catalyst-support axis direction even when cracks occur in the catalyst-support circumference direction in the surface electrodes.

Solution to Problem

An electrically heated catalyst device according to an aspect of the present invention includes:

a catalyst support including a ceramics, on which a catalyst is supported;

a pair of surface electrodes disposed on an outer surface of the catalyst support, the surface electrodes being disposed opposite to each other and extending in an axial direction of the catalyst support; and

a wiring line that externally supplies electric power to the surface electrodes, in which

the catalyst support is electrically heated through the surface electrodes, and

a wrought member made of metal is buried in the surface electrodes, the wrought member extending in the axial direction of the catalyst support.

It is possible to provide an electrically heated catalyst device capable of maintaining the spreading of electric currents in the catalyst-support axis direction even when cracks occur in the catalyst-support circumference direction in the surface electrodes.

The wrought member is preferably is one of a mesh, wires, and a perforated plate. In this way, the spreading of electrical currents in the catalyst-support axis direction can be reliably maintained.

Further, the surface electrodes are preferably formed by thermal spraying.

Further, a hollow space is preferably formed between the catalyst support and the wrought member. In this way, the thermal stress is alleviated.

Further, the wrought member preferably includes a bonding region to which the surface electrode is bonded and a non-bonding region to which the surface electrode is not bonded. In this way, the thermal stress is alleviated.

Further, in order to enable the electrically heated catalyst device to be used in an environment at a temperature of 800° C. or above, the wrought member is preferably made of one of a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy.

The connection area in the surface electrode in which the wiring line is connected is preferably located at the center in the axial direction of the catalyst support.

The ceramics preferably includes SiC.

Further, the surface electrode preferably includes a Ni—Cr alloy (with a Cr content of 20 to 60 mass %) or an MCrAlY alloy (M is at least one material selected from Fe, Co and Ni).

A manufacturing method of an electrically heated catalyst device according to an aspect of the present invention is a manufacturing method of an electrically heated catalyst device that electrically heats a catalyst support including a ceramics, on which a catalyst is supported, through surface electrodes formed on a surface of the catalyst support, the manufacturing method includes:

forming a pair of the surface electrodes disposed on an outer surface of the catalyst support, the surface electrodes being disposed opposite to each other and extending in an axial direction of the catalyst support; and

connecting a wiring line that externally supplies electric power to the surface electrodes,

in which in the forming of the surface electrodes, a wrought member made of metal is buried in the surface electrodes, the wrought member extending in the axial direction of the catalyst support.

The wrought member is preferably one of a mesh, wires, and a perforated plate.

Further, in the forming of the surface electrodes, a thermal-spraying is preferably performed over the wrought member put on the catalyst support.

Further, a hollow space is preferably formed between the catalyst support and the wrought member.

In the forming of the surface electrodes, a surface of the wrought member put on the catalyst support is preferably roughened before the thermal-spraying.

In the roughening, a bonding region to which the surface electrode is bonded is preferably roughened and a non-bonding region to which the surface electrode is not bonded is preferably not roughened.

Advantageous Effects of Invention

According to the present invention, it is possible to provide an electrically heated catalyst device capable of maintaining the spreading of electric currents in the catalyst-support axis direction even when cracks occur in the catalyst-support circumference direction in the surface electrodes.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective view of an electrically heated catalyst device **100** according to a first exemplary embodiment;

FIG. **2** is a plane view of an electrically heated catalyst device **100** according to a first exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **3** is a cross section taken along the cutting line III-III in FIG. **2**;

FIG. **4** is a cross section taken along the cutting line IV-IV in FIG. **2**;

FIG. **5** is a photograph of a cross section at a bonding interface between a catalyst support **20** and a surface electrode **31**;

FIG. **6** is a graph showing the dependence of the minimum temperature within a catalyst support **20** on supplied electric power;

FIG. **7** is a graph showing the dependence of the maximum temperature difference within a catalyst support **20** on supplied electric power;

FIG. **8** is a plane view of an electrically heated catalyst device **200** according to a second exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **9** is a cross section taken along the cutting line IX-IX in FIG. **8**;

FIG. **10** is a plane view of an electrically heated catalyst device **200** according to a modified example of a second exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **11** is a plane view of an electrically heated catalyst device **200** according to a modified example of a second exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **12** is a plane view of an electrically heated catalyst device **200** according to a modified example of a second exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **13** is a plane view of an electrically heated catalyst device **300** according to a third exemplary embodiment as viewed from directly above a surface electrode **31**;

FIG. **14**A is a plane view of a perforated metal plate **31***d* of an electrically heated catalyst device **300** according to a third exemplary embodiment;

FIG. **14**B is a plane view of a perforated metal plate **31***d* of an electrically heated catalyst device **300** according to a modified example of a third exemplary embodiment; and

FIG. **14**C is a plane view of a perforated metal plate **31***d* of an electrically heated catalyst device **300** according to a modified example of a third exemplary embodiment.

DESCRIPTION OF EMBODIMENTS

Specific exemplary embodiments to which the present invention is applied are explained hereinafter in detail with reference to the drawings. However, the present invention is not limited to the exemplary embodiments shown below. Further, for clarifying the explanation, the following descriptions and the drawings are simplified as appropriate.

(First Exemplary Embodiment)

Firstly, an electrically heated catalyst device according to a first exemplary embodiment is explained with reference to FIGS. **1** to **4**. FIG. **1** is a perspective view of an electrically heated catalyst device **100** according to the first exemplary embodiment. FIG. **2** is a plane view of the electrically heated catalyst device **100** according to the first exemplary embodiment as viewed from directly above a surface electrode **31**. FIG. **3** is a cross section taken along the cutting line III-III in FIG. **2**, and is a cross section in an area in which a fixing layer **33** is formed. FIG. **4** is a cross section taken along the cutting line IV-IV in FIG. **2**.

The electrically heated catalyst device **100** is provided, for example, on an exhaust path of an automobile or the like, and purifies an exhaust gas discharged from the engine. As shown in FIG. **1**, the electrically heated catalyst device **100** includes a catalyst support **20**, surface electrodes **31**, wiring lines **32**, and fixing layers **33**. Note that although FIG. **2** shows a positional relation among the catalyst support **20**, the wiring lines **32**, and the fixing layers **33** in one of the surface electrodes **31**, the other surface electrode **31** also has a similar positional relation.

The catalyst support **20** is a porous member on which a catalyst such as platinum and palladium is supported. Further, since the catalyst support **20** is electrically heated itself, the catalyst support **20** is composed of a conductive ceramics, for example, SiC (silicon carbide). As shown in FIG. **1**, the catalyst support **20** has roughly a cylindrical external shape and has a honeycomb structure inside thereof. As indicated by an arrow, an exhaust gas passes through the catalyst support **20** in the axial direction of the catalyst support **20**.

As shown in FIG. **1**, the surface electrodes **31** are a pair of electrodes that are disposed opposite to each other on the outer surface of the catalyst support **20**. Further, as shown in FIG. **2**, each of the surface electrodes **31** has a rectangular plane shape and extends in the catalyst-support axis direction. Note that the surface electrodes **31** are not formed in the areas near both ends in the catalyst-support axis direction. The surface electrodes **31** are connected to a power supply such as a battery through the wiring lines **32**. Further, an electric current is supplied to the catalyst support **20** through the surface electrodes **31** and the catalyst support **20** is thereby electrically heated. Note that one of the surface electrodes **31** serves as a positive pole and the other surface electrode **31** serves as a negative pole. However, either one of the surface electrodes **31** can serve as a positive pole or a negative pole. That is, there is no restriction on the direction of the current flowing through the catalyst support **20**.

Note that as shown in FIG. **2**, a metal mesh **31***a* is buried inside each of the surface electrodes **31** as a wrought member made of metal that is disposed so as to extend in the catalyst-support axis direction. Further, as can be seen in the cross sections shown in FIGS. **3** and **4**, the metal mesh **31***a* is buried inside each of the surface electrodes **31**. Details of the metal mesh **31***a* are explained later.

As shown in FIG. **1**, a plurality of wiring lines **32** are disposed on each of the pair of surface electrodes **31**. The plurality of wiring lines **32** are a ribbon-like sheet metal that is physically in contact with and electrically connected to the surface electrode **31**. The wiring lines **32** are preferably made of, for example, a heat-resistant (oxidation-resistant) alloy such as a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy so that they can be used at a high temperature equal to or higher than 800° C.

Further, as shown in FIG. **2**, the plurality of wiring lines **32** extend over the entire formation area of the surface electrode **31** in the catalyst-support circumference direction. Further, all of the wiring lines **32** protrude and extend from one side of the formation area of the surface electrode **31**, and are integrated into one piece at the end of the protrusions. Further, the plurality of wiring lines **32** are arranged at roughly regular intervals along the catalyst-support axis direction on the surface electrode **31**. In the electrically heated catalyst device **100** according to this exemplary embodiment, 12 wiring lines **32** are disposed in the central area in the axis direction of the catalyst support **20** on each of the surface electrodes **31**. Needless to say, the number of the wiring lines **32** is not limited to 12 and can be arbitrarily determined.

Note that the catalyst support **20** is fixed and supported on an exhaust path by using a mat (not shown) made of heat-resistant material near both ends of the catalyst support **20** in the catalyst-support axis direction. If the wiring lines **32** come into contact with the mat, friction occurs between the wiring lines **32** and the mat due to the thermal cycle load, and thus raising a possibility that the wiring lines **32** could be broken. Therefore, the wiring lines **32** are disposed only in the central area in the catalyst-support axis direction in which the mat is not formed.

As shown in FIGS. **1** and **2**, the wiring lines **32** are fixed to the surface electrode **31** by the fixing layers **33**. Note that FIG. **3** is a cross section taken along the cutting line III-III in FIG. **2**, and is a cross section in an area in which a fixing layer **33** is formed. As shown in FIG. **3**, the surface electrode **31** is a thermal-sprayed film having a thickness of about 50 to 200 μm, formed on the outer surface of the catalyst support **20**. The surface electrode **31** is physically in contact with and electrically connected to the catalyst support **20**.

The fixing layers **33** are button-shaped thermal-sprayed films that are formed so as to cover the wiring lines **32** in order to fix the wiring lines **32** to the surface electrode **31**. Note that the fixing layers **33** are formed in the button-shape in order to alleviate the stress that is caused by the difference between the linear expansion coefficient of the fixing layers **33** and the surface electrode **31**, which are thermal-sprayed metal-based films, and the linear expansion coefficient of the catalyst support **20**, which is made of a ceramics. That is, by reducing the size of each of the fixing layers **33** as much as possible, the above-described stress is alleviated. As shown in FIG. **2**, the fixing layers **33** are physically in contact with and electrically connected to the wiring lines **32** and the surface electrode **31**.

Further, as shown in FIG. **1**, two fixing layers **33** are provided for each wiring line **32** in such a manner that the fixing layers **33** fix the wiring line **32** to the surface electrode **31** roughly at both ends in the catalyst-support circumference direction. Further, as shown in FIG. **3**, the fixing layers **33** are arranged in such a manner that fixing layers **33** disposed on mutually-neighboring wiring lines **32** are staggered from each other in the catalyst-support circumference direction. In other words, on each of the surface electrodes **31**, **12** fixing layers **33** are disposed in a staggered arrangement in the catalyst-support axis direction along each of the two long sides of the surface electrode **31** having a rectangular shape.

The thermal-sprayed films forming the surface electrodes **31** and the fixing layers **33** need to be made of metal-based material in order to let an electric current pass therethrough as in the case of the wiring lines **32**. As a metal forming the matrix of the thermal-sprayed film, since it needs to be robust enough for use at a high temperature equal to or higher than 800° C., a metal having excellent oxidation resistance at a high temperature such as a Ni—Cr alloy (with a Cr content of 20 to 60 mass %) and an MCrAlY alloy (M is at least one material selected from Fe, Co and Ni) is preferable. Note that each of the above-described Ni—Cr alloy and the MCrAlY alloy may contain other alloy elements. The thermal-sprayed films forming the surface electrodes **31** and the fixing layers **33** may be porous films. By using porous films, the function of alleviating the stress is improved.

With the above-described structure, in the electrically heated catalyst device **100**, the catalyst support **20** is electrically heated between the pair of surface electrodes **31** and the catalyst supported on the catalyst support **20** is thereby activated. In this way, unburned HC (hydrocarbon), CO (carbon monoxide), NOx (nitrogen oxide), and the like contained in an exhaust gas that passes through the catalyst support **20** are removed by the catalytic reaction.

Next, details of the metal mesh **31***a* are explained. As shown in FIG. **2**, the metal mesh **31***a* is buried under roughly the entire surface of the formation area of the surface electrode **31**. The structure like this can be formed by putting the metal mesh **31***a* on the catalyst support **20** and then forming the surface electrode **31** composed of a thermal-sprayed film over this metal mesh **31***a*.

With the structure like this, in the electrically heated catalyst device **100** according to this exemplary embodiment, since the metal mesh **31***a* extending in the catalyst-support axis direction is buried in each of the surface electrodes **31**, the spreading of electric currents in the catalyst-support axis direction through this metal mesh **31***a* can be maintained even when cracks occur in the catalyst-support circumference direction in the surface electrode **31**. Therefore, the area near the center in the axis direction of the catalyst support **20** is not intensively heated, and thus making it possible to avoid the thermal-stress cracking due to this intensive heating.

Further, the catalyst support **20** is fixed and supported on an exhaust path by using a mat (not shown) made of heat-resistant material near its both ends in the catalyst-support axis direction. If the metal mesh **31***a* is disposed on the surface of the surface electrode **31**, friction occurs between the metal mesh **31***a* and the mat due to the thermal cycle load, and thus raising a possibility that the metal wires forming the metal mesh **31***a* could be broken. However, since the metal mesh **31***a* according to this exemplary embodiment is buried in the surface electrode **31**, the friction never occurs between the metal mesh **31***a* and the mat even by the thermal cycle load. Therefore, there is no risk that the metal wires forming the metal mesh **31***a* are broken.

Note that the metal mesh **31***a* is physically in contact with and electrically connected to the surface electrode **31**. The metal mesh **31***a* is preferably formed, for example, from wires having a diameter of 0.1 mm or narrower, made of a heat-resistant (oxidation-resistant) alloy such as a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy and so that they can be used at a high temperature equal to or higher than 800° C. As described above, the metal mesh **31***a* is fixed to the catalyst support **20** by putting the metal mesh **31***a* on the catalyst support **20** and then forming the surface electrode **31** composed of a thermal-sprayed film over this metal mesh **31***a*. Therefore, the metal mesh **31***a* is preferably weaved in such a manner that certain space is formed between neighboring metal wires, such as a plain weave, a flat-top weave, a diamond weave, and a hexagonal weave. Further, the mesh size is preferably 50 or smaller.

Note that FIG. **5** is a photograph of a cross section at a bonding interface between the catalyst support **20** and the surface electrode **31**. As can be seen from FIG. **5**, since the surface electrode **31** is formed by thermal spraying performed over the metal mesh **31***a*, a hollow space **35** is formed immediately below the metal mesh **31***a*. That is, the metal mesh **31***a* is not bonded to the catalyst support **20**. Since the hollow space (non-bonding region) **35** is formed immediately below the metal mesh **31***a* as described above, the thermal stress that is caused by the difference between the linear expansion coefficient of the surface electrode **31** and the metal mesh **31***a* made of metallic material and that of the catalyst support **20** made of the ceramic material can be alleviated. In particular, since the hollow space **35** is formed so as to conform to the shape of the metal mesh **31***a*, the surface electrode **31** has a pseudo-segment structure. Therefore, the thermal stress can be effectively restrained.

Note that in order to bond the surface electrode **31**, which is a thermal-sprayed film, to the metal mesh **31***a*, it is necessary to roughen the surface of the metal mesh **31***a* by performing a shot-blast process before the surface electrode **31** is thermal-sprayed. The bonding region between the metal mesh **31***a* and the surface electrode **31** can secure the current-carrying property. Meanwhile, the non-bonding region between the metal mesh **31***a* and the surface electrode **31** can alleviate the thermal stress between the surface electrode **31** and metal mesh **31***a*. Therefore, the shot-blast process may be performed on the surface of the metal mesh **31***a* in such a manner that part of the metal mesh **31***a* is not treated by the shot-blast process by using a mask or the like. In this way, it is possible to optimize the balance between the above-mentioned current-carrying property and the alleviation of the thermal stress.

Next, advantageous effects of an example of the electrically heated catalyst device **100** according to this exemplary embodiment are explained with reference to FIGS. **6** and **7**. The comparative example is identical to the example except that the comparative example does not include the metal mesh **31***a*. FIG. **6** is a graph showing the dependence of the minimum temperature within the catalyst support **20** on supplied electric power. FIG. **7** is a graph showing the dependence of the maximum temperature difference within the catalyst support **20** on supplied electric power. In FIGS. **6** and **7**, the horizontal axis indicates supplied electric power (kW). The vertical axis of FIG. **6** indicates minimum temperatures (° C.) within the catalyst support **20** and the vertical axis of FIG. **7** indicates maximum temperature differences (° C.) within the catalyst support **20**. In both graphs, specific numerical values are omitted. Therefore, they indicate qualitative tendencies.

As shown in FIG. **6**, the supplied electric power required for raising the minimum temperature within the catalyst support **20** to or above a target value in the example of the electrically heated catalyst device **100** according to this exemplary embodiment is smaller than that in the comparative example even in the initial state. In addition, the supplied electric power hardly increases even in the "after-use" state corresponding to a state after a 30 km traveling. In contrast to this, in the comparative example, the supplied electric power increases significantly in the "after-use" state in comparison to that in the initial state as indicated by an arrow in the graph.

As shown in FIG. **7**, in order to lower the maximum temperature difference within the catalyst support **20** to or below a target value, it is desirable that the supplied electric power is as small as possible. Therefore, the larger the maximum supplied electric power with which the maximum temperature difference can be lowered to or below the target value is, the better the electrically heated catalyst device is. In the example, the above-mentioned maximum supplied electric power is larger than that of the comparative example even in the initial state. In addition, the maximum supplied electric power does not decrease even in the after-use" state. In contrast to this, in the comparative example, the maximum supplied electric power decreases significantly in the after-use" state in comparison to that in the initial state as indicated by an arrow in the graph.

Note that it is necessary to supply the supplied electric power with which both the target value for the minimum temperature and the target value for the maximum temperature difference within the catalyst support **20** shown in FIGS. **6** and **7** are satisfied. However, in the case of the comparative example, any supplied electric power cannot satisfy both target values simultaneously in the after-use" state. In contrast to this, in the case of the example, there is supplied electric power with which both target values are simultaneously satisfied even in the after-use" state. That is, in the example, even when the surface electrodes **31** have deteriorated (corresponding to "after-use state" in FIGS. **6** and **7**), the spreading of electric currents in the catalyst-support axis direction can be secured by the metal mesh **31***a*. Therefore, the minimum temperature within the catalyst support **20** can be maintained at a high temperature and the maximum temperature difference can be maintained at a small value. In the comparative example, when the surface electrodes **31** have deteriorated (corresponding to "after-use state" in FIGS. **6** and **7**), the spreading of electric currents in the catalyst-support axis direction is hampered. Therefore, the central area in the axis direction of the catalyst support **20** is intensively heated while both ends in the catalyst-support axis direction cannot be easily heated. Therefore, the minimum temperature within the catalyst support **20** is lowered and the maximum temperature difference increases significantly.

(Second Exemplary Embodiment)

Next, an electrically heated catalyst device according to a second exemplary embodiment is explained with reference to FIGS. **8** and **9**. FIG. **8** is a plane view of an electrically heated catalyst device **200** according to the second exemplary embodiment as viewed from directly above a surface electrode **31**. FIG. **9** is a cross section taken along the cutting line IX-IX in FIG. **8**. As shown in FIG. **8**, in the electrically heated catalyst device **200** according to the second exemplary embodiment, metal wires **31***b* are buried in place of the metal mesh **31***a* according to the first exemplary embodiment as a wrought member made of metal that is disposed so as to extend in the catalyst-support axis direction, inside the surface electrode **31**. Further, as can be also seen from FIG. **9**, metal wires **31***b* having a rectangular shape in cross section are buried inside the surface electrode **31**. Needless to say, the metal wires **31***b* may have other cross-section shapes such as a circle.

As shown in FIG. **8**, a plurality of metal wires **31***b* are buried under roughly the entire surface of the formation area of the surface electrode **31**. Each of the metal wires **31***b* is buried over the entire formation area in the catalyst-support axis direction in the surface electrode **31**. Further, the plurality of lines **31***b* are arranged at roughly regular intervals along the catalyst-support circumference direction on each of the surface electrodes **31**. In the example shown in FIG. **8**, seven metal wires **31***b* are disposed in parallel inside the surface electrode **31**. Needless to say, the number of the metal wires **31***b* is not limited to any particular number. Similarly to the metal mesh **31***a* according to the first exemplary embodiment, the metal wires **31***b* are preferably made of, for example, a heat-resistant (oxidation-resistant) alloy such as a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy. As for the cross-section size, when the metal line is circular in cross section, the diameter is preferably 0.2 mm or smaller. Further, when the metal line is rectangular in cross section, the thickness is preferably 0.2 mm or smaller and the width is preferably 5 mm or smaller.

With the structure like this, in the electrically heated catalyst device **200** according to this exemplary embodiment, since the metal wires **31***b* extending in the catalyst-support axis direction are buried in each of the surface electrodes **31**, the spreading of electric currents in the catalyst-support axis direction through these metal wires **31***b* can be maintained even when cracks occur in the catalyst-support circumference direction in the surface electrode **31**. Therefore, the area near the center in the axis direction of the catalyst support **20** is not intensively heated, and thus making it possible to avoid the thermal-stress cracking due to this intensive heating.

Further, similarly to the metal mesh **31***a* according to the exemplary embodiment, since the metal wires **31***b* are buried in the surface electrode **31**, the friction never occurs between the metal wires **31***b* and the mat even by the thermal cycle load. Therefore, there is no risk that the metal wires **31***b* are broken.

Note that since the surface electrode **31** is formed by thermal spraying performed over the metal wires **31***b*, hollow spaces (not shown) are formed immediately below the metal wires **31***b*. That is, the metal wires **31***b* are not bonded to the catalyst support **20**. Since the hollow spaces (non-bonding regions) are formed immediately below the metal wires **31***b* as described above, the thermal stress that is caused by the difference between the linear expansion coefficient of the surface electrode **31** and the metal wires **31***b* made of metallic material and that of the catalyst support **20** made of the ceramic material can be alleviated.

Note that in order to bond the surface electrode **31**, which is a thermal-sprayed film, to the metal wires **31***b*, it is necessary to roughen the surfaces of the metal wires **31***b* by performing a shot-blast process before the surface electrode **31** is thermal-sprayed. The bonding regions between the metal wires **31***b* and the surface electrode **31** can secure the current-carrying property. Meanwhile, the non-bonding regions between the metal wires **31***b* and the surface electrode **31** can alleviate the thermal stress between the surface electrode **31** and metal wires **31***b*. Therefore, the shot-blast process may be performed on the surface of the metal wires **31***b* in such a manner that parts of the metal wires **31***b* are not treated by the shot-blast process by using a mask or the like. In this way, it is possible to optimize the balance between the above-mentioned current-carrying property and the alleviation of the thermal stress. The other structure is similar to that of the first exemplary embodiment, and therefore its explanation is omitted.

Next, modified examples of the second exemplary embodiment are explained with reference to FIGS. **10** to **12**. Each of FIGS. **10** to **12** is a plane view of an electrically heated catalyst device **200** according to a modified example of the second exemplary embodiment as viewed from directly above a surface electrode **31**. Each of these electrically heated catalyst devices **200** shown in FIGS. **10** to **12** can provide similar advantageous effects to those of the electrically heated catalyst device **200** shown in FIG. **8**.

As shown as another example of the electrically heated catalyst device **200** in FIG. **10**, the metal wires **31***b* may not be disposed in the central area in the catalyst-support axis direction in the surface electrode **31** in which the wiring lines **32** are connected. That is, the metal wires **31***b* may be divided into two sections and these two sections may be disposed on both sides of the surface electrode **31** with the central area in the catalyst-support axis direction of the surface electrode **31** interposed therebetween.

As shown as another example of the electrically heated catalyst device **200** in FIG. **11**, metal lines **31***c* extending in the catalyst-support circumference direction may be also disposed in addition to the metal wires **31***b* extending in the catalyst-support axis direction. The configuration like this resembles the metal mesh **31***a* according to the first exemplary embodiment.

As shown as another example of the electrically heated catalyst device **200** in FIG. **12**, the metal wires **31***b* may not be disposed in the central area in the catalyst-support axis direction in the surface electrode **31** in which the wiring lines **32** are connected. That is, the metal wires **31***b* may be divided into two sections and these two sections may be disposed on both sides of the surface electrode **31** with the central area in the catalyst-support axis direction of the surface electrode **31** interposed therebetween. Further, the metal wires **31***b* may be disposed in an oblique direction(s) with respect to the catalyst-support axis direction. In the example shown in FIG. **12**, four metal wires **31***b* are arranged in a radial pattern, extending from the central area in the catalyst-support axis direction of the surface electrode **31** toward the four corners of the surface electrode **31**.

(Third Exemplary Embodiment)

Next, an electrically heated catalyst device according to a third exemplary embodiment is explained with reference to FIGS. **13** and **14**A. FIG. **13** is a plane view of an electrically heated catalyst device **300** according to the third exemplary embodiment as viewed from directly above a surface electrode **31**. FIG. **14**A is a plane view of a perforated metal (punching metal) plate **31***d* of the electrically heated catalyst device **300** according to the third exemplary embodiment. As shown in FIG. **13**, in the electrically heated catalyst device **300** according to the third exemplary embodiment, a perforated metal plate **31***d* is buried in place of the metal mesh **31***a* according to the first exemplary embodiment as a wrought member made of metal that is disposed so as to extend in the catalyst-support axis direction, inside the surface electrode **31**.

As shown in FIG. **13**, one perforated metal plate **31***d* is buried under roughly the entire surface of the formation area of the surface electrode **31**. As shown in FIG. **14**A, a large number of punched-out holes are arranged in an orderly pattern in the perforated metal plate **31***d*. Similarly to the metal mesh **31***a* according to the first exemplary embodiment, the perforated metal plate **31***d* is preferably made of, for example, a heat-resistant (oxidation-resistant) alloy such as a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy. Note that the perforated metal plate **31***d* may be divided into multiple sections.

With the structure like this, in the electrically heated catalyst device **300** according to this exemplary embodiment, since the perforated metal plate **31***d* extending in the catalyst-support axis direction is buried in each of the surface electrodes **31**, the spreading of electric currents in the catalyst-support axis direction through this perforated metal plate **31***d* can be maintained even when cracks occur in the catalyst-support circumference direction in the surface electrode **31**. Therefore, the area near the center in the axis direction of the catalyst support **20**, in which the wiring lines **32** are connected, is not intensively heated, and thus making it possible to avoid the thermal-stress cracking due to this intensive heating.

Further, similarly to the metal mesh **31***a* according to the exemplary embodiment, since the perforated metal plate **31***d* is buried in the surface electrode **31**, the friction never occurs between the perforated metal plate **31***d* and the mat by the thermal cycle load. Therefore, there is no risk that the perforated metal plate **31***d* is broken.

Note that since the surface electrode **31** is formed by thermal spraying performed over the perforated metal plate **31***d*, a hollow space (not shown) is formed immediately below the perforated metal plate **31***d*. That is, the perforated metal plate **31***d* is not bonded to the catalyst support **20**. Since the hollow space (non-bonding region) is formed immediately below the perforated metal plate **31***d* as described above, the thermal stress that is caused by the difference between the linear expansion coefficient of the surface electrode **31** and the perforated metal plate **31***d* made of metallic material and that of the catalyst support **20** made of the ceramic material can be alleviated. In particular, since the hollow space is formed so as to conform to the shape of the perforated metal plate **31***d*, the surface electrode **31** has a pseudo-segment structure. Therefore, the thermal stress can be effectively restrained.

Note that in order to bond the surface electrode **31**, which is a thermal-sprayed film, to the perforated metal plate **31***d*, it is necessary to roughen the surfaces of the perforated metal plate **31***d* by performing a shot-blast process before the surface electrode **31** is thermal-sprayed. The bonding regions between the perforated metal plate **31***d* and the surface electrode **31** can secure the current-carrying property. Meanwhile, the non-bonding regions between the perforated metal plate **31***d* and the surface electrode **31** can alleviate the thermal stress between the surface electrode **31** and perforated metal plate **31***d*. Therefore, the shot-blast process may be performed on the surface of the perforated metal plate **31***d* in such a manner that part of the perforated metal plate **31***d* is not treated by the shot-blast process by using a mask or the like. In this way, it is possible to optimize the balance between the above-mentioned current-carrying property and the alleviation of the thermal stress. The other structure is similar to that of the first exemplary embodiment, and therefore its explanation is omitted.

Next, modified examples of the third exemplary embodiment are explained with reference to FIGS. **14**B and **14**C. Each of FIGS. **14**B and **14**C is a plane view of a perforated metal plate **31***d* of an electrically heated catalyst device **300** according to a modified example of a third exemplary embodiment. By using either one of the perforated metal plates **31***d* shown in FIGS. **14**B and **14**C, similar advantageous effects to those of the electrically heated catalyst device **300** shown in FIG. **13** can be achieved.

As shown in FIG. **14**B, the perforated metal plate **31***d* may have punched-out holes having a rectangular shape. Further, as shown in FIG. **14**C, the perforated metal plate **31***d* may have punched-out holes having a diamond shape. Note that the shape of the punched-out holes is not restricted to any particular shape. That is, they may have any shape.

Note that the present invention is not limited to the above-described exemplary embodiments, and various modifications can be made without departing from the spirit of the present invention. For example, metal fibers having a diameter of 0.01 to 0.15 mm may be buried as a wrought member made of metal that is disposed so as to extend in the catalyst-support axis direction, inside the surface electrode.

REFERENCE SIGNS LIST

20 CATALYST SUPPORT
31 SURFACE ELECTRODE
31A METAL MESH
31B, **31**C METAL WIRE
31D PERFORATED METAL PLATE
32 WIRING LINE
33 FIXING LAYER
35 HOLLOW SPACE
100, **200**, **300** ELECTRICALLY HEATED CATALYST DEVICE

The invention claimed is:

1. An electrically heated catalyst device comprises:
- a catalyst support comprising a ceramics, on which a catalyst is supported;
- a pair of surface electrodes disposed on an outer surface of the catalyst support, the surface electrodes being disposed opposite to each other and extending in an axial direction of the catalyst support; and
- a wiring line that externally supplies electric power to the surface electrodes, wherein
- the catalyst support is electrically heated through the surface electrodes, and
- a wrought member made of metal is buried in the surface electrodes, the wrought member extending in the axial direction of the catalyst support.

2. The electrically heated catalyst device according to claim **1**, wherein the wrought member is one of a mesh, wires, and a perforated plate.

3. The electrically heated catalyst device according to claim **1**, wherein the surface electrodes are formed by thermal spraying.

4. The electrically heated catalyst device according to claim **3**, wherein a hollow space is formed between the catalyst support and the wrought member.

5. The electrically heated catalyst device according to claim **3**, wherein the wrought member comprises:
- a bonding region to which the surface electrode is bonded; and
- a non-bonding region to which the surface electrode is not bonded.

6. The electrically heated catalyst device according to claim **1**, wherein the wrought member is made of one of a stainless-steel-based alloy, a Ni-based alloy, and a Co-based alloy.

7. The electrically heated catalyst device according to claim **1**, wherein a connection area in the surface electrode in which the wiring line is connected is located at a center in the axial direction of the catalyst support.

8. The electrically heated catalyst device according to claim **1**, wherein the ceramics comprises SiC.

9. The electrically heated catalyst device according to claim 1, wherein the surface electrode comprises a Ni-Cr alloy (with a Cr content of 20 to 60 mass %) or an MCrAlY alloy (M is at least one material selected from Fe, Co and Ni).

10. A manufacturing method of an electrically heated catalyst device that electrically heats a catalyst support comprising a ceramics, on which a catalyst is supported, through surface electrodes formed on a surface of the catalyst support, the manufacturing method comprising:

forming a pair of the surface electrodes disposed on an outer surface of the catalyst support, the surface electrodes being disposed opposite to each other and extending in an axial direction of the catalyst support; and

connecting a wiring line that externally supplies electric power to the surface electrodes,

wherein in the forming of the surface electrodes, a wrought member made of metal is buried in the surface electrodes, the wrought member extending in the axial direction of the catalyst support.

11. The manufacturing method of an electrically heated catalyst device according to claim 10, wherein the wrought member is one of a mesh, wires, and a perforated plate.

12. The manufacturing method of an electrically heated catalyst device according to claim 10, wherein in the forming of the surface electrodes, a thermal-spraying is performed over the wrought member put on the catalyst support.

13. The manufacturing method of an electrically heated catalyst device according to claim 12, wherein a hollow space is formed between the catalyst support and the wrought member.

14. The manufacturing method of an electrically heated catalyst device according to claim 12, wherein in the forming of the surface electrodes, a surface of the wrought member put on the catalyst support is roughened before the thermal-spraying.

15. The manufacturing method of an electrically heated catalyst device according to claim 14, wherein in the roughening, a bonding region to which the surface electrode is bonded is roughened and a non-bonding region to which the surface electrode is not bonded is not roughened.

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